International Journal of Environmental Monitoring and Analysis
2024, Vol. 12, No. 2, pp. 21-28
https://doi.org/10.11648/j.ijema.20241202.11

Research Article

Validation of Fertilizer Requirement Map for Teff (*Eragrostis teff* (*Zucc.*)) at Lume District, East Shewa Zone, Oromia, Ethiopia

Tilahun Abera*, Reta Worku, Tilahun Firomsa

Batu Soil Research Center, Oromia Agricultural Research Center, Finfine, Ethiopia

Abstract

Ethiopia's teff production, a key cereal crop, has long suffered from blanket fertilizer recommendations that fail to account for the diverse soil conditions across the country. This often leads to suboptimal yields, falling short of the crop's true potential. To address this challenge, Batu Soil Research Center embarked on a ground breaking initiative: developing a phosphorus fertilizer requirement map specifically tailored to the Lume district. To validate the effectiveness of this map, field experiments were conducted across nine peasant associations within the district. Four different fertilizer treatments were compared: unfertilized control plots, plots receiving the conventional blanket recommendation of a uniform 100/100 NPS/Urea application, plots applying phosphorus based on the newly created map (P-map), and plots receiving phosphorus calculated based on individual soil analysis (P-required). The results were striking. P-map emerged as the clear winner, driving the highest yields of both grain (2178 kg ha^{-1}) and biomass (6639 kg ha^{-1}) compared to all other treatments. This impressive performance translated to a significant improvement in harvest index as well, reaching 34.11%. Notably, P-map surpassed not only the control group but also the blanket recommendation, highlighting the limitations of a one-size-fits-all approach. Economic analysis further solidified the case for P-map. For farmers in Lume district, adopting this map-based approach promises a 100% marginal rate of return, making it a highly profitable investment. This economic benefit, coupled with the substantial yield improvements, paves the way for a more sustainable and prosperous future for teff cultivation in the region. In conclusion, the fertilizer requirement map developed by Batu Soil Research Center holds immense potential for revolutionizing teff production in Ethiopia. By moving away from blanket recommendations and embracing a precision-driven approach, farmers in Lume district and beyond can unlock the full potential of this valuable crop, boosting their yields, income, and food security.

Keywords

Blanket Recommendation, P-map, P-required, Teff, Fertilizer Requirement Map

1. Introduction

Teff is an indigenous crop in Ethiopia that exists in white, red, and mixed varieties. It is rich in essential amino acids, slowly digesting carbohydrates, essential fatty acids, minerals, vitamins, fibers, and other components. Teff has a low glycemic index and is enriched in essential nutrients, making it a promising food for the prevention and management of

*Corresponding author: tileabera3@gmail.com (Tilahun Abera)

Received: 11 December 2023; **Accepted:** 6 January 2024; **Published:** 20 March 2024

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diabetes. Teff grass is rapidly growing, high-quality forage that can be a competitive summer annual option for producers in water-limited areas with a short growing season the yield of Teff is constrained by various factors such as plant lodging, declining soil fertility, leaching, and low fertilizer use. However, the application of specific blended fertilizers can improve nutrient uptake and fertilizer use efficiency, leading to yield increment [1-3].

Soil test based crop response phosphorus calibration study is important for Teff crop in Ethiopia because it helps determine the optimum phosphorus fertilizer application rate for maximizing Teff yield. The study conducted by Habtemariam in the Amhara region found that the application of both nitrogen (N) and phosphorus (P) fertilizers significantly improved the grain yield of teff. They recommended different types of blended fertilizers containing N and P for the region. This information can be used to establish site-specific soil test based phosphorus fertilizer recommendations for Teff as well. Additionally, the study by Mesfin and Tadesse in Southern Ethiopia assessed the effect of different rates of blended fertilizer on common bean yield and identified economically feasible rates. This information can be extrapolated to Teff cultivation as well. Therefore, soil test based crop response phosphorus calibration studies provide valuable insights for optimizing Teff crop production in Ethiopia [4-6].

Traditionally, site-specific soil management strives for economically optimal fertilizer application rates. However, determining the precise phosphorus requirement for each field, known as p-required, presents a significant challenge for many farmers. Soil sampling and laboratory analysis, essential steps in this process, are often cost-prohibitive, time-consuming, and inaccessible for resource-constrained smallholder. To address this critical barrier, a novel fertilizer requirement map for Teff cultivation has been developed. This map leverages geo-statistical techniques, primarily Ordinary Kriging, to predict the fertilizer needs of un sampled locations based on readily available data like soil phosphorus levels, critical phosphorus levels (Pc), and phosphorus requirement factors (pf) established through prior calibration studies for Teff. This simplified approach empowers farmers and development agents to directly access fertilizer recommendations for their specific fields, circumventing the complexities of p-required calculations.

However, maps generated using typical sampling and interpolation methods can sometimes exhibit varying degrees of accuracy [7, 8]. Therefore, rigorous validation through field testing is crucial before broad-scale implementation. This project aims to validate the Teff fertilizer requirement map for Lume district through comparative yield analysis. We will compare the yield and yield components of crops grown with fertilizers prescribed by the map versus those receiving fertilizer rates calculated using traditional p-required methods. This robust validation process will provide compelling evidence to support the map's effectiveness and pave the way for widespread adoption. The experiment was conducted with the following objectives:

1. To Validate and introduce the fertilizer requirement map for Teff production in Lume district:
2. To populirize soil test-based Teff response and phosphorus fertilizer recommendation:

By achieving these objectives, this project intends to revolutionize Teff cultivation in Lume district, empowering farmers with accurate, accessible fertilizer recommendations and promoting sustainable soil management practices for long-term agricultural success.

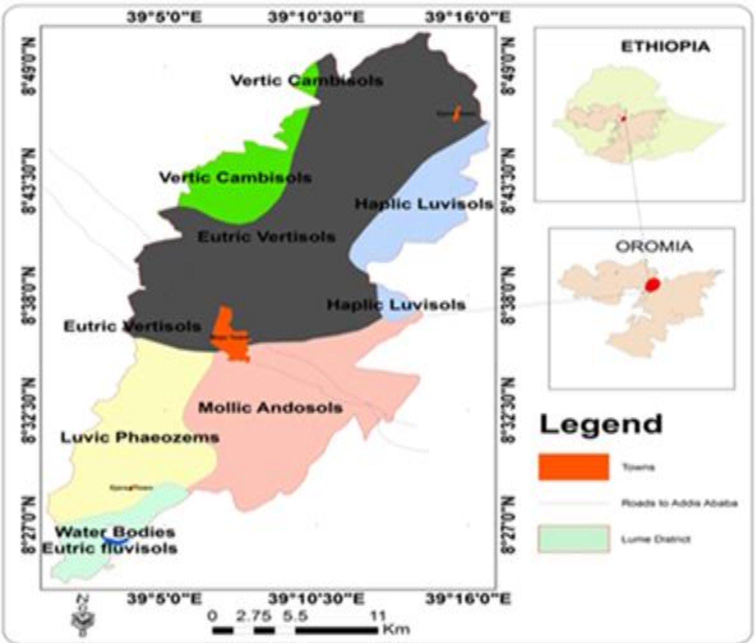

Figure 1. *The geographic location of the Lume district.*

2. Materials and Methods

2.1. Description of the Study Area

The experiment took place on 14 farms across 9 peasant associations in Lume District, within the vast Oromia region of Ethiopia. Situated in the East Shewa Zone, Lume lies roughly 73 kilometers east of the capital, Addis Ababa. Geographically, the district stretches between 80 °27'00" and 80 °49'00" North and 39 °05'00" to 39 °16'00" East, encompassing a total area of 67,514.73 hectares. The terrain itself varies significantly, with elevations ranging from 1,590 meters to 2,512 meters above sea level, averaging at 1,909 meters.

2.2. Experimental Materials

Crops: The experiment utilized the "Boset" variety of teff, specifically chosen due to its development and release by the Debrezeit Agricultural Research Centre.

Fertilizer: NPS fertilizer (19% nitrogen, 38% phosphorus pentoxide, and 7% sulfur) served as the source of nitrogen, phosphorus, and sulfur. Additionally, the recommended optimal nitrogen rate of 46 kg N/ha was applied.

Tech Tools: Global Positioning System (GPS) technology and ArcGIS software were employed for accurate field data collection and analysis.

2.3. Methods

2.3.1. Map Development

1. Soil Sampling: The first step involved carefully collecting representative soil samples from each designated mapping unit during the base map preparation phase.
2. Laboratory Analysis: These samples were then transported to the Batu Soil laboratory for thorough analysis to determine their NPK content, pH, CEC, EC, and texture.
3. Geo-referencing and Map Creation: The laboratory results were meticulously geo-referenced and integrated with ArcGIS 10.1 software. Geo-statistical interpolation, primarily Ordinary Kriging, was employed to create a comprehensive set of soil maps based on the analyzed data.

2.3.2. Verification of Fertilizer Recommendations

1. Sampling Site Selection: To ensure the accuracy of the fertilizer requirement map, a rigorous process of independent soil sampling and analysis was conducted. Teff-growing Peasant Associations were identified based on the map's recommendations, specifically those with varying fertilizer application rates and large land units. Within these areas, 9 farmers' fields were selected with the consent of the established Farmer Research Extension Groups.
2. Sample Collection: From each field, 20-25 composite soil samples were collected from a depth of 0-20 cm and carefully labelled for transportation to the laboratory.

2.3.3. Laboratory Analysis

1. Preparation: Soil samples were air-dried, ground, and sieved through a 2 mm sieve for uniformity.
2. Parameters Measured: soil pH, electrical conductivity (EC meter), Available phosphorus nd soil texture were all measured. [14, 15]

2.3.4. Phosphorus Requirement Calculation

Using the equation PR = (PC - PO) * Pf, each sample's phosphorus requirement (PR) for Teff cultivation was calculated, where PC is the phosphorus critical level for Teff, PO is the measured available phosphorus in the soil, and Pf is the phosphorus requirement factor for Teff. This comprehensive process of soil sampling, analysis, and phosphorus requirement calculation played a vital role in validating the fertilizer requirement map's recommendations, ultimately ensuring accurate and data-driven phosphorus application for optimal teff production in the region.

Table 1. Methods of fertilizer application from fertilizer requirement map for Teff at Lume district.

No	Selected color	Pc- Po	Pf	P applied (kgha^{-1}) = (Pc-Po)*Pf	P_20_5(kgha^{-1}) = P*2.3	NPS (kgha^{-1}) = p_20_5*100/38	urea (kgha^{-1})
1		3.95-5	3.65	14 -18	33 -42	87 - 110	100
2		5-6	3.65	18 -22	42 - 50	110 - 133	100
3		6-7	3.65	22 -26	50 - 59	133 - 155	100
4		7-8	3.65	26 -29	59 - 67	155 - 177	100
5		8-9	3.65	29-33	67 - 76	177 - 199	100

No	Selected color	Pc- Po	Pf	P applied ($kgha^{-1}$) = (Pc-Po)*Pf	P_2O_5($kgha^{-1}$) = P*2.3	NPS ($kgha^{-1}$) = p_2O_5*100/38	urea ($kgha^{-1}$)
6		9-10.38	3.65	33 -38	76 - 87	199 - 481	100

Note: if your phosphorus fertilizer sources will be DAP/TSP divides p205$_x$100/46

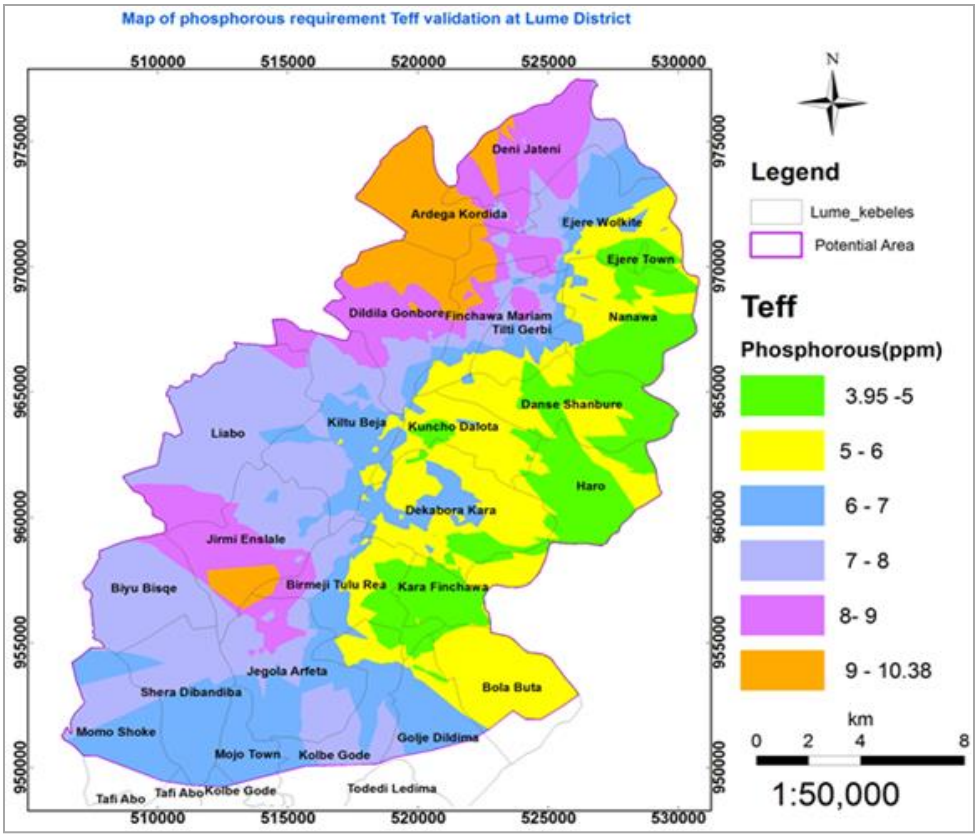

Figure 2. Validated fertilizer requirement map of Teff at Lume district.

2.4. Building Farmer Research Teams and Conducting Field Trials

This study involved a two-year, multi-location research project across Lume District. To ensure effective data collection and farmer engagement, the following steps were taken:

2.4.1. Establishing Farmer Research Extension Groups (FREGs)

1. Selection: Nine Peasant Associations (PAs) were chosen each year based on accessibility and potential for the study.
2. Group Formation: Within each PA, nine FREGs were established, each consisting of 10-15 members. Gender and youth inclusion were prioritized, with at least 40% female representation. The development agent facilitated this process.
3. Model Farmer Selection: From each FREG, one model farmer was selected based on their willingness to provide land for Teff production. Local development agents played an active role in this selection.

2.4.2. Data Collection and Analysis

Soil Sampling: A composite soil sample (0-20 cm depth) was collected from each farmer's land using the zigzag method. These samples were analysed at the Batu soil laboratory to determine available phosphorus levels, which influenced fertilizer application rates for Teff.

2.4.3. Field Experiment

1. Land Preparation: Farmers, under the close supervision of researchers and development agents, prepared the land using the traditional ox plow. This cost-sharing approach involved farmers providing the land and managing field operations, while the research center

provided agricultural inputs, technical support, training, and guidance.

2. Planting and Data Collection: Seeds and fertilizers were applied according to pre-determined rates. Throughout the growing season, data was collected from each location with the active participation of development agents and farmers. Regular group discussions were held to assess their knowledge and skills, identify gaps, and adjust training needs accordingly.

2.4.4. Knowledge Sharing and Dissemination

Mini Field Day: To showcase the project's findings and encourage adoption, a mini field day was organized at the crop's maturity stage. This event served as a platform for farmers, researchers, and extension agents to share knowledge and experiences. By establishing FREGs, involving farmers in every step of the research process, and actively disseminating information, this study ensured robust data collection, engaged farmer participation, and potentially influenced the adoption of improved practices in teff cultivation.

2.5. Treatments and Experimental Design

To validate the efficacy of the fertilizer requirement map, researchers designed a robust experiment with four distinct treatment groups:

1. Teff Phosphorus Fertilizer Requirement (PR): This group received customized applications of phosphorus fertilizer based on the calculated PR for each location. These calculations used the soil's available phosphorus content, a critical phosphorus level for teff, and a specific phosphorus requirement factor.
2. P-map: This group relied on the newly developed fertilizer map itself, with each plot receiving phosphorus fertilizer according to the map's recommended rate for that specific location.
3. Blanket Recommendation: Serving as a reference point, this group received a standard application of 100 kg NPK and 100 kg Urea, regardless of individual soil conditions.
4. Control: To establish a baseline, this group received no fertilizer application.

Each treatment was replicated nine times across different locations, with plots measuring 10 m x 10 m and spaced strategically. Nitrogen fertilizer, in the form of Urea (46% N), was applied at the recommended rate of 46 kg N ha^{-1} for all treatments except the control [9]. For plots receiving NPS fertilizer, the nitrogen content within the mixture was accounted for to prevent over-application.

This well-designed experiment, with its diverse treatment groups and meticulous replication, provides a valuable platform for comparing different phosphorus application strategies. It can evaluate the effectiveness of the map-based approach, validate the calculated PR method, and compare both to the traditional blanket recommendation and a no-fertilizer control. Through careful analysis of the resulting data, researchers can determine the most efficient and profitable method for applying phosphorus fertilizer for optimal teff production in the region.

Table 2. *Quantity of fertilizers treatment used for Validation of fertilizer requirement map for teff crop in kg/ha.*

sites	p-required		p- map		Blanket		Control
	Po (ppm)	**P applied *Pc=13, pf=3.65***	**Po (ppm)**	**P applied *Pc=13, pf=3.65***	**NPS**	**Urea**	**No fertilizer**
1	6.56	23.51	7.2	21.17	100	100	0
2	10.54	8.98	4.6	30.66	100	100	0
3	9.56	12.56	5.9	25.92	100	100	0
4	8.02	18.18	5.9	25.92	100	100	0
5	15.46	0	5.9	25.92	100	100	0
6	10.26	10.00	7.2	21.17	100	100	0
7	12.1	3.29	4.6	30.66	100	100	0
8	16.7	0	5.9	25.92	100	100	0
9	8.42	16.72	7.2	21.17	100	100	0

Whereas, po= initial soil phosphorus, Pc= critical soil phosphorous, pf= phosphorous requirement factor, Yld= yield, Bm = biomass, p- map= phosphorus applied from fertilizer requirement map, p-required = $(Pc-P0)*P_f$); Blanket= farmer practice

2.6. Management of the Experiment

Prior to sowing in mid-July 2016, the experimental site underwent traditional three-time plowing and meticulous leveling. Treatments received designated full-dose NPS fertilizer and half the nitrogen at sowing, followed by the remaining nitrogen at mid-tillering. All plots received identical care in other agronomic practices. At harvest maturity, crops were reaped, sun-dried to constant weight, and threshed for yield measurement. This rigorous preparation and uniform management created a controlled environment for comparing the effectiveness of diverse fertilizer application strategies.

2.7. Data Collection and Measurement

Above-ground dry biomass yield: was determined from plants harvested from the net plot area after sun drying to a constant weight and expressed in kg ha^{-1}.

Grain yield: was taken by harvesting and threshing the grain yield from the net plot area. The yield was adjusted to 12.5% moisture content and expressed as yield in kg ha^{-1}.

Harvest index (HI): was calculated as the ratio of grain yield per plot to total above-ground dry biomass yield per plot expressed as a percent.

2.8. Statistical Analysis

The data were subjected to analysis of variance (ANOVA) as per the experimental design using [16]. The Least Significance Difference (LSD) at a 5% level of probability was used to determine differences between treatment means.

2.9. Partial Budget Analysis

Data's were exposed a two-step approach to identify the most profitable fertilizer strategies. First, using a method from CIMMYT (1988), they categorized treatments as "dominated" (less profitable) or "undominated" (potentially profitable) based on net benefits and costs. For the undominated treatments, they calculated a % Marginal Rate of Return (MRR) to compare the increase in net benefits with the accompanying increase in cost, ultimately seeking the strategies with the best trade-off for farmers' wallets. This rigorous analysis ensured they could pinpoint the most economically viable options for sustainable and profitable teff cultivation.

Dominance Analysis: Researchers employed a specific technique outlined by [10]. To pinpoint the most economically promising treatments among those tested. This method involves comparing treatments based on their net benefits and total variable costs. Dominated vs. Undominated Treatments:- Treatments deemed less profitable due to lower net benefits or higher costs were discarded, categorized as "dominated." The remaining treatments, those offering superior economic potential, were labeled "undominated." Marginal Rate of Return (MRR) Calculation: To further evaluate the profitability of undominated treatments, researchers calculated their MRRs. This metric measures the percentage increase in net benefits resulting from a unit increase in total variable costs. The formula used was:

$$MRR (\%) = [(NBb - NBA) / (TCVb - TCVa)] * 100$$

where:

NBA = Net benefit of the treatment with the lower total variable cost (TCVa)

NBb = Net benefit of the treatment with the higher total variable cost (TCVb)

3. Results and Discussion

Table 3. *Grain yield, Biomass, and Harvest Index of Teff variety as influenced by the different quantities of phosphorus fertilizer application.*

Treatments	GY(kg ha^{-1})	BM (kg ha^{-1})	HI (%)
P- required	2061 ^{a}	6111 ^{ab}	36.11 ^{a}
P- map	2178 ^{a}	6639 ^{a}	34.11 ^{a}
Blanket	1694 ^{b}	5556 ^{b}	30.97 ^{a}
Control	711 ^{c}	3472 ^{c}	22.42 ^{b}
LSD (0.05)	349	852.3	5.514
CV (%)	21.9	16.1	26.3

Means within a column followed by the same letter are not significantly different at a 5% level of significance according to Fisher protected LSD test; BM= Biomass yield; GY = Grain yield; HI% = Harvest index; Pr = phosphorus required (25 kg P ha^{-1}); p- map= phosphorus predicted (10 kg P ha^{-1}), Blanket (100/100 NPS/Urea kg ha^{-1}, control (no fertilizer application)

The Analysis of Variance indicates that Teff Yield and Biomass were highly significantly different from all treatments at $P<0.01$ except for P-map, which was insignificantly different. However, the Harvest index was insignificantly ($p<0.05$) influenced by the different rates of phosphorus fertilizer application except for the control one (Table 2).

As indicated in Table 2, The highest (2178 kg ha^{-1}) grain Yield, (6639 kg ha^{-1}) Biomass yield was recorded by P-map except for (36.11%) harvest index which was recorded by P-required while the lowest(711 kg ha^{-1}) grain Yield, (3472 kg ha^{-1}) Biomass yield and (22.42%) harvest index were recorded by nil fertilizer application. P-map increased Teff yield grain and biomass yield by 138.26% and 60.02% over control, 28.57%, and 19.49% over the blanket, respectively. Moreover, the highest grain yield and biomass recorded by

P- the map were statistically at par with the succeeding p-required rate of phosphorus fertilizer application (Table 2). The result is also in line with [11] who reported that, the application of P fertilizer with nitrogen enhanced teff grain yield as it increases from 0-30 kg ha^{-1} and recorded the highest grain yield of (1681.1 kg ha^{-1}) at an application rate of 46 kg N ha^{-1} and 10 kg P ha^{-1} while the minimum grain yield of Teff was recorded from the unfertilized plots.

The result is in line with [12] who reported that Produced maps of soil macro- and micro-nutrients could potentially be used for delineating areas of nutrient deficiency/sufficiency relative to nutrient requirements and as an input to crop modeling.

This result is also parallel with [13] who reported that biomass yield, grain yield, and harvest index of Teff increased with an increased level of phosphate fertilizer and the optimum grain yield was obtained by applying a phosphate fertilizer rate of 46 kg P_2O_5 ha^{-1}. Similarly, the result is in line with [11] who reported that the application of Phosphorus fertilizer from 0-40 kg ha^{-1} increases teff panicle length and higher panicle length may have also a positive contribution to the grain and straw yields since it has a positive correlation to grain yield.

4. Partial Budget Analysis

Optimizing fertilizer use for teff farmers in Lume district involved identifying treatments with the best return on investment. A marginal analysis revealed that both the "P-map" (phosphorus application based on the fertilizer requirement map) and "P-required" treatments were financially viable options for farmers.

The P-map treatment offered the highest net benefit at 39,545 Birr ha⁻¹, boasting a remarkable 12.5x return on investment for every Birr invested (1,250% MRR). For those who prefer a simpler approach, the "P-required" treatment, tailored to the specific phosphorus needs of the Boset variety, yielded a net benefit of 14,220 Birr ha⁻¹with a still respectable 11.15x return on each Birr invested. Therefore, both treatments surpass the minimum acceptable 100% MRR, making them economically attractive for farmers. The choice ultimately comes down to individual preference: P-map for maximum profitability or P-required for a simpler, variety-specific approach. This analysis provides valuable insights for teff farmers in Lume district, empowering them to make informed decisions about fertilizer use and maximize their returns.

Table 4. Partial budget and marginal analysis of treatment applied over nine sites for Teff.

Treatments	P (kg ha^{-1})	N (kg ha^{-1})	Adjusted grain yield by 10% (kg ha^{-1})	Gross Benefit (Birr ha^{-1})	Total variable cost (Birr ha^{-1})	Net return (Birr ha^{-1})	MRR %
Control	0	0	711	14220	0	14220	-
Blanket	16.5	65	1694	33880	2949	31366	D
P-required	25	17.3	2178	43560	2595	40965	331
P-map	10	11.6	2061	41220	1675	39545	1215

Where, NPS cost = 14.54 Birr kg^{-1}, UREA cost = 10.60 Birr $kg^{-1}$of N, NPS, Teff grain per ha= 20 Birr kg^{-1}, MRR (%) = Marginal rate of return, D= Dominated treatment, Control = unfertilized

5. Conclusion and Recommendation

This study sheds light on a critical challenge in Ethiopian agriculture: low teff productivity due to declining soil fertility and ineffective fertilizer use. Traditionally, "blanket" fertilizer recommendations disregarding local variations have led to inefficient resource utilization and environmental concerns. This research offers a promising solution through the use of fertilizer requirement maps and soil test-based approaches for precise phosphorus application.

Field trials across nine locations revealed the effectiveness of both P-map and P-required treatments in significantly boosting teff yield and biomass compared to the control and blanket application. P-map emerged as the top performer in terms of yield, while both strategies exceeded the minimum acceptable economic return for farmers. Therefore, we recommend the adoption of either P-map or P-required methods for teff cultivation in Lume district. The map-based approach offers convenience and precision tailored to specific locations, while the variety-specific P-required method provides a simpler option for farmers familiar with the Boset variety. Ultimately, the choice depends on individual preferences and resource availability.

By embracing these innovative approaches, Lume district farmers can optimize fertilizer use, achieve higher teff yields, and contribute to sustainable and profitable agriculture in Ethiopia.

Conflicts of Interest

The authors declare no conflicts of interest.

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